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Minimizing Real Power Losses Via Optimal Reactive Power Allocation and Distributed Generation Using Grey Wolf Optimizer

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Abstract

An emphasis is placed on the optimal location and sizing of distributed generation and reactive power compensation to minimize real power loss in the Radial Distribution Network. This paper uses the Reconfiguration Method to determine the optimal locations of reactive power compensators and distributed generation units. Grey Wolf Optimizer (GWO) is the technique that is used to select the optimal sizing of reactive power compensators and distributed generation units. Two approaches are used: the meta-heuristics optimization technique GWO, and the Reconfiguration Method to determine the optimal location and size of shunt capacitors and distribution generators. This paper aims to minimize the real power losses, improve the voltage profiles, and enhance the voltage stability index on distribution networks by adding distributed generators and shunt capacitors with the optimal size. The IEEE 33-bus system, as a standard power system, is utilized to validate the suggested technique. Simulation results with various case studies show that the placement of distributed generating units and reactive power compensators in power distribution networks reduces the stress on the line loads and produces a sizable loss reduction with a favorable voltage profile.

Keywords: Distributed generation; Grey Wolf Optimizer; IEEE 33-bus system; Optimal allocation; Reactive power compensation; Real power Loss minimization.

1. Introduction

The constant increase of system demand and the massive integration of intermittent energy sources may lead to large uncertainties and degrade the stability of the grid in terms of frequency and voltages [1]-[4].

Transformers are used to connect the high-voltage transmission networks to the low-voltage distribution networks, which supply clients with lower-voltage electricity. Compared to high-voltage networks, distribution network lines have significant power losses because of their higher current and lower voltage [5]. Energy expenses are growing, and the voltage profile throughout the distribution feeder is falling. The distribution network's total power loss results from real and reactive power losses. The primary cause of power loss is the quantity of reactive current required to provide reactive power to network components, which regulates the system's voltage. Real power loss is a significant loss since it lowers the effectiveness of power transmission and modifies the voltage profile. Reducing power loss in distribution networks is more crucial than in transmission systems. The distribution of electric power is a crucial element in reducing power loss and increasing the overall efficacy of the electric power transmission system. Power losses at distribution networks are said to be responsible for up to 13% of all energy waste [6]. Radial lines occasionally have limited capacity; therefore, it is important to consider other options to satisfy future load requirements while maintaining supply quality and dependability [7]-[8]. Because many parts of the distribution network, including motors and transformers, are inductive, the power factor (PF) lags.

As a result, the network's power factor will be trailing, lowering system voltage, increasing losses, and reducing capacity. Some of these problems are resolved with the use of shunt capacitors. In addition to lowering power losses, shunt capacitors enhance the system's voltage stability, power factor, and profile. It is crucial to ensure that DG units are operated effectively without compromising performance, supply quality, or system dependability. Another choice to consider when organizing an extension of the distribution system is shunt capacitors. Shunt capacitors are frequently employed to modify reactive power. Any reduction in power losses is advantageous to distribution utilities. Therefore, the most crucial consideration while building and operating distributed generation systems is preventing losses.

The literature indicates that reactive power injection using shunt capacitors can reduce system energy losses and feeder stress and increase supply reliability. Shunt capacitor placement and sizing should be carefully considered to avoid voltage rise issues and reduce DG unit operating costs. Various optimization techniques were used on the power systems in order to identify and resolve the various issues. The Hunger Games Search (HGS) [9]-[10], Differential Evolution (DE) [11], Improved Differential Evolution (IDE) [12]-[13], Harris Hawks Optimization (HHO) [14]-[15], Slime Mould Algorithm (SMA) [16], Modified Artificial Bee Colony (MABC) [17], and Grey Wolf Optimizer (GWO) [18]-[19] are a few examples used to solve the optimal power flow. In addition, numerous optimization techniques, such as the Manta Ray Foraging Optimization algorithm (MRFO) [20], Genetic Algorithms (GA) [21], widow optimization (BWO) [22], and Improved Whale Optimizer (IWOA) [23] have been proposed for the ideal allocation (location and sizing) of distributed generation (DG) in distribution networks to reduce power losses. Recognizing that reactive power compensation (Qc) and distribution generation (DG) can provide both reactive and actual power, the current work also examines the optimal sizes and placements for these components. This paper seeks to maximize placement and sizing while concurrently lowering reactive power losses, boosting the voltage profiles at all buses, and increasing the voltage stability index with satisfied constraints (equality and inequality) to minimize real power losses within the distribution network.

The convergence of the proposed algorithms is efficient, requiring fewer iterations to reach optimal solutions than other optimization techniques reported in the literature. This method demonstrated GWO's effectiveness and superiority on the IEEE 33-bus standard radial power system. This paper's proposed objective function (OF) is the real power losses. Three situations have been used to optimize this OF. The first case involves determining the best size and location for a shunt capacitor (SC) in the distribution network, then choosing the ideal goal function (minimization of real power losses). Reactive power output from SC [MVAr] serves as the system's injection power in this situation. The optimal size and positioning of distributed generation (DG) to the distribution network are determined in the first scenario, and then the optimal objective function is chosen. In this case, the system's injection power comes from the active power output of the RES [MW]. The second scenario involves choosing the best objective function after simultaneously figuring out where and how best to install distributed generation (DG) and shunt capacitors (SC) in the distribution network. Reactive [MVAr] and active [MW] power production from SC and DG provide the system's injection power in this scenario. The primary contributions can be summed up as follows:

1. The authors used one of the most popular optimization techniques, inspired by Grey Wolf, to minimize the power losses in the real power of the distribution network.
2. GWO is the proposed algorithm for determining the optimal size of a shunt capacitor (SC) and distributed generator (DG).
3. The authors used the reconfiguration methods (RM) to determine the optimal placement of the shunt capacitor (SC) and the distributed generator (DG).
4. The authors compared both approaches (GWO and RM) to determine the optimal location and size of SC and DG.
5. Real power losses are the objective function proposed in this paper.
6. The authors have applied the approaches (GWO and RM) to an IEEE 33-bus radial distribution system with four case studies (initial case, installing single SC, installing single DG, installing single SC and DG, simultaneously).

This paper's main format is formulating the problems comprising the objective function and the constraints in Section 2. The suggested methodology includes the techniques for determining the ideal placement and size, summarized in Section 3. The simulation results and discussion for your comments are covered in Section 4, along with advice on where to place and how big to make the IEEE 33-bus system to minimize real power losses. Ultimately, Section 5 presents the conclusions.

2. Problem Formulation

The primary objective of this study is to find the ideal SC and DG capacity and placement to reduce real power losses on distribution networks and meet constraint requirements.

2.1. Power Flow Equations

The basic single-line schematic of a radial distribution network is shown in Fig. 1. It is used to determine the power flow in distribution networks, where A and B, respectively, can be used to represent the transmitting and receiving buses. While (1) and (2) can be used to determine the real and reactive power.

$$P_a = P_b + P_{l,b} + R_{a,b}\left(\frac{\left(P_b + P_{l,b}\right)^2 + \left(Q_b + Q_{l,b}\right)^2}{|V_b|^2}\right) \tag{1}$$

$$Q_a = Q_b + Q_{l,b} + X_{a,b}\left(\frac{\left(P_b + P_{l,b}\right)^2 + \left(Q_b + Q_{l,b}\right)^2}{|V_b|^2}\right) \tag{2}$$

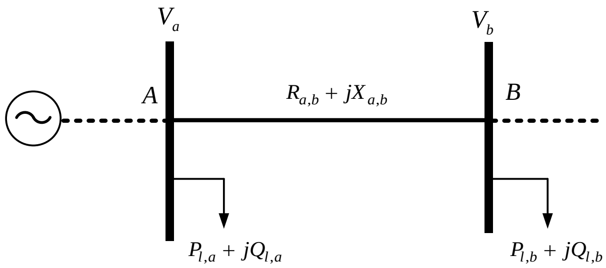

Figure 1. The equivalent circuit of RDN.

P_a and Q_a are the active and reactive output powers at bus A, P_b, Q_b, and V_b are the real power, reactive power, and voltage at bus B, respectively. $P_{l,b}$, and $Q_{l,b}$ are the real and reactive loads at bus B, respectively. $R_{a,b}$, and $X_{a,b}$ represent the resistance and reactance of lines A and B, respectively.

2.2. Objective Function

Installing SC and DG in radial distribution networks is to reduce the current passing through the lines in the feeder. This reduction reduced the real power losses, improved the voltage profiles, and enhanced the voltage stability index. Therefore, the main aim of this study is to minimize the real power losses on distribution lines, which can be calculated as follows:

$$P_{Loss}=\sum_{k=1}^{N_{nl}} G_i\left(V_i^2+V_j^2-2V_iV_j\cos\delta_{i,j}\right) \quad (3)$$

G_i is the transfer conductance.

The voltage deviation (VD) serves as the primary criterion for evaluating the security of the voltage. Therefore, it can be expressed in terms of voltage deviation by the following equation [24]:

$$VD=\sum_{i=1}^{N_{PQ}}\left|V_i-1.0\right| \quad [p.u.] \quad (4)$$

The primary goal of calculating the voltage stability index is to find the bus most vulnerable to failure in the radial distribution system [25].

$$VSI=2V_iV_j-V_j-2V_j\left(PR+QX\right)-\left|Z\right|^2\left(P^2+Q^2\right) \quad (5)$$

2.3. Constraints

The equality and inequality restrictions listed below limit the above-described objective function:

2.3.1. Power balance

According to Equations (1) and (2), each system branch's flow of active and reactive power must comply with the equality condition for power balance.

$$P_{substation}+P_{DG}=\sum P_{load}+\sum P_{loss} \quad (6)$$

$$Q_{substation}+Q_{DG}+Q_{SC}=\sum Q_{load}+\sum Q_{loss} \quad (7)$$

$P_{substation}$, P_{DG}, P_{load}, and P_{loss} are the real power of the substation, DG, load, and losses, respectively. $Q_{substation}$, Q_{DG}, Q_{SC}, Q_{load}, and Q_{loss} are the reactive power of the substation, DG, SC, load, and losses, respectively.

2.3.2. Inequality constraints

Inequality constraints provide limits or bounds on specific variables or expressions. Usually, they specify areas or requirements that the variables need to meet. One way to characterize the inequality restrictions is as follows:

- **Bus voltage**: According to the inequality constraint, the voltage at each bus must be within the predefined limits.
-
- (8)
- Line current: Due to the inequality

$$V_q^{\min}\le V_q\le V_q^{\max} \qquad q\in S_B$$

- restriction, every branch's current flow cannot exceed its thermal limit.

$$I_{pq}\le I_{pq}^{rated} \qquad \forall \quad p \quad and \quad q\in S_B \quad (9)$$

- **DG capacity:** According to the inequality constraint, distributed generation's (DG) capacity cannot exceed a particular percentage of the network's total feeder load.

$$\sum_{q\in S_B}\sqrt{\left(P_q^{DG}\right)^2+\left(Q_q^{DG}\right)^2}=\sum_{q\in S_B}\sqrt{\left(P_q^{L}\right)^2+\left(Q_q^{L}\right)^2} \quad (10)$$

- **Capacitor capacity:** Since the capacity cannot exceed the network's total reactive power load, the inequality restriction must be followed.

$$\sum_{q\in S_B}Q_q^C=\sum_{q\in S_B}Q_q^L \quad (11)$$

V_q^{min} and V_q^{Max} indicate the voltages' lowest and highest values at bus q, represented in the range (0.95-1.05). I_{pq}^{rated} represents the thermal limit between nodes q and p. $\cos\emptyset_q$ is the power factor (PF) of the distributed generation (DG) at the *q-th* bus.

3. Proposed Methodology

Two approaches are proposed to find the optimal position and size depending on the kind of connection. The reconfiguration method is applied to determine the ideal position. Grey Wolf Optimizer (GWO) algorithm is applied to determine the ideal sizing. These methods can summarized up as follows:

3.1. Reconfiguration Method (RM)

The reconfiguring method is the suggested strategy for determining the best placement in a single SC and DG connection. The reconfiguration method determines which bus is optimal by positioning the source (SC or DG) at each bus and figuring out the actual power losses there. The bus with the lowest real power loss value is the ideal bus, and all bus losses combined will be ranked. The primary actions that need to be taken while using distinct single DG and SC are:

- Calculate the real power loss at each bus after connecting DG and SC, thus selecting the optimal size based on GWO.
- The bus with the lowest real power loss should link the SC unit and the DG. When employing a single DG and SC at the same time, the primary actions that need to be taken are:
- The pre-selected buses nominated that are selected separately will be the candidates to connect DG and SC units simultaneously.
- The size of the DG and SC unit will be determined according to GWO.

3.2. Grey Wolf Optimizer (GWO)

A new heuristic optimization tool called the "Grey Wolf Optimizer" (GWO) was inspired by the social behaviors of members of the Canidae family, specifically grey wolves [26]. As shown in Fig. 2, grey wolves are divided into four levels based on leadership level: beta (β), alpha (α), delta (δ), and omega (ω). In GWO, alpha denotes the solution that best fits the user. At the same time, beta and delta rank second and third, respectively, and omega represents the solutions offered after the suggestions of the first three wolves to arrive at the best answer. When hunting a grey wolf, the primary steps are

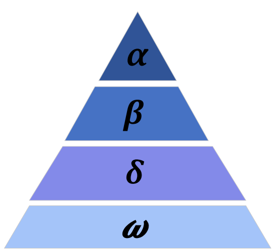

Figure 2. Grey wolf hierarchy in GWO

3.2.1. Encircling prey

This procedure is the greatest way to encircle prey in a circular region while hunting. Grey wolves circle their prey in the following equations:

$$E = \left| D \cdot Z_p(t) - Z(t) \right| \quad (12)$$

$$Z(t+1) = Z_p(t) - C \cdot E \quad (13)$$

$$C = 2c \cdot r_1 - c \quad (14)$$

$$D = 2 \cdot r_2 \quad (15)$$

The coefficients in this case are C and D. While *t* denotes the current iteration. The location vectors of the grey wolf and the prey are denoted by Z and Y_p, respectively. C decreasing adjustment is made to *c* from 2 to 0. Two random vectors in [0, 1] are r_1 and r_2.

3.2.2. Hunting

During this operation, the vector *Z(t+1)* updates its location every time in the search space based on the ideal positions of the leadership level (alpha, beta, and delta). The positions of the other agents in the search space will be updated to determine which search agents are the best. The agents' positions will update using the top three previously saved and applied solutions. The behavior of the hunter can be described using the formulas below:

$$E_\alpha = \left| D_1 \cdot Z_\alpha - Z \right|, E_\beta = \left| D_2 \cdot Z_\beta - Z \right|, E_\delta = \left| D_3 \cdot Z_\delta - Z \right| \quad (16)$$

$$Z_1 = Z_\alpha - C_1 \cdot E_\alpha, Z_2 = Z_\beta - C_2 \cdot E_\beta, Z_3 = Z_\delta - C_3 \cdot E_\delta \quad (17)$$

$$Z(t+1) = {Z_1 + Z_2 + Z_3} \big/ 3 \quad (18)$$

Z_1, Z_2, and Z_3 can denote the estimated position based on alpha, beta, and delta, respectively. The modified final position is denoted by *Z(t+1)*.

3.2.3. Attacking

When the target stops moving, grey wolves begin their final phase of the hunting process by attacking their prey. The process's mathematical formula can be understood by progressively lowering the value of b from 2 to 0 with each iteration. The behavior of an attacking prey can represent the GWO's local search.

3.2.4. Searching

α, β, and δ wolves' positions determine where the grey wolves begin their hunt for prey. Grey wolves will split up during this phase and then come together to attack their victim. They suggest that the wolves need to look for better prey because |C|>1. This process can represent the exploration of GWO. Fig. 3 shows the flowchart of the GWO algorithm.

3.3. Implementation of GWO to Determine the Optimal Size

The following steps are considered to find the optimal size:

Step 1: Create the initial population and all GWO parameters.

Step 2: Setting the control variables, such as the active power output of DG and the reactive power output of source VAR compensation.

Step 3: The control variables will be changed randomly within the minimum and maximum value ranges.

Step 4: Determine the goal function's fitness function values for each iteration, and set the iteration number to 1.

Step 5: Update the parameter values of GWO, such as C and D.

Step 6: Calculate the values of E_α, E_β, and E_δ

Step 7: Find the fitness values until they reach the last iteration.

Step 8: Rearrange the positions of α, β, and δ vectors of GWO in the population.

Step 9: Until the maximum number of iterations is achieved, repeat steps 6 through 8 again.

4. Simulation results

The significance of the proposed algorithm GWO is examined for two distribution networks. The suggested approach was used in MATLAB to calculate the ideal SC and DG unit sizes. Tests have been conducted on IEEE 33-bus standard radial distribution systems to verify the proposed method (GWO). The IEEE 33-bus power system's single line diagram is shown in Fig. 4. This system's parameters are shown in [27]. The IEEE 33-bus system's line and bus dates are shown in Table 1. The system has 33 buses, 32 lines, a 3.72 MW real power load, and a 2.3 MVA reactive power load. The voltage and power basis systems are 12.66 kV and 10 MVA, respectively [28]. Using the line and load data, the Newton-Raphson technique calculates load flow and determines voltage magnitude, phase angle, active power output at the slack bus, real and reactive power losses, and line flow. The Newton-Raphson method (NRM) is applied to the power flow calculations for the scenarios under analysis. Distributed generation (DG) in the simulation tests provides only active power and runs at unity power factor. The SC provides reactive power, and active power is provided by the DG. Shunt capacitors (SC) and distributed generation (DG) units, either separately or in combination, are assigned in this study. It can be assigned to any value that falls between the minimum and maximum values that relate to it.

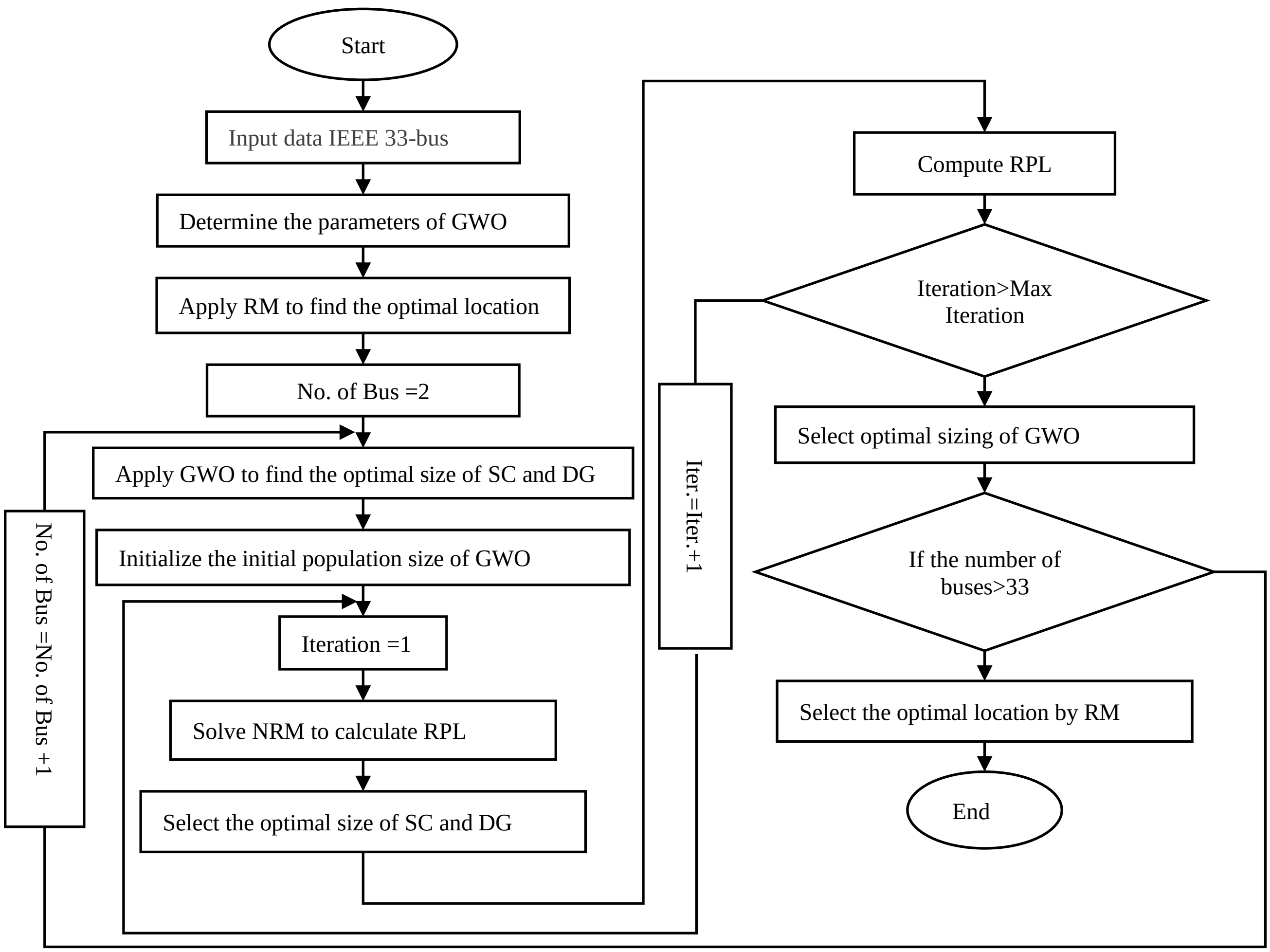

Figure 3. Flowchart of proposed approaches on RDN 33-bus.

Table 1. The Bus and Line data of the IEEE 33 bus system.

Bus	Bus Data Load P [kW]	Q [kVAr]	Line Data Bus From	To	R [p.u.]	X [$p.u.$]
1	0	0	1	2	0.005753	0.002932
2	100	60	2	3	0.03076	0.015667
3	90	40	3	4	0.022836	0.01163
4	120	80	4	5	0.023778	0.01211
5	60	30	5	6	0.051099	0.044112
6	60	20	6	7	0.01168	0.038608
7	200	100	7	8	0.044386	0.014668
8	200	100	8	9	0.064264	0.04617
9	60	20	9	10	0.065138	0.04617
10	60	20	10	11	0.012266	0.004056
11	45	30	11	12	0.02336	0.007724
12	60	35	12	13	0.091592	0.072063
13	60	35	13	14	0.033792	0.04448
14	120	80	14	15	0.036874	0.032818
15	60	10	15	16	0.046564	0.034004
16	60	20	16	17	0.080424	0.107378
17	60	20	17	18	0.045671	0.035813
18	90	40	2	19	0.010232	0.009764
19	90	40	19	20	0.093851	0.084567
20	90	40	20	21	0.02555	0.029849
21	90	40	21	22	0.04423	0.058481
22	90	40	3	23	0.028152	0.019236
23	90	50	23	24	0.056028	0.044243
24	420	200	24	25	0.055904	0.043743
25	420	200	6	26	0.012666	0.006451
26	60	25	26	27	0.017732	0.009028
27	60	25	27	28	0.066074	0.058256
28	60	20	28	29	0.050176	0.043712
29	120	70	29	30	0.031664	0.016128
30	200	600	30	31	0.060795	0.060084
31	150	70	31	32	0.019373	0.02258
32	210	100	32	33	0.021276	0.033081
33	60	40				

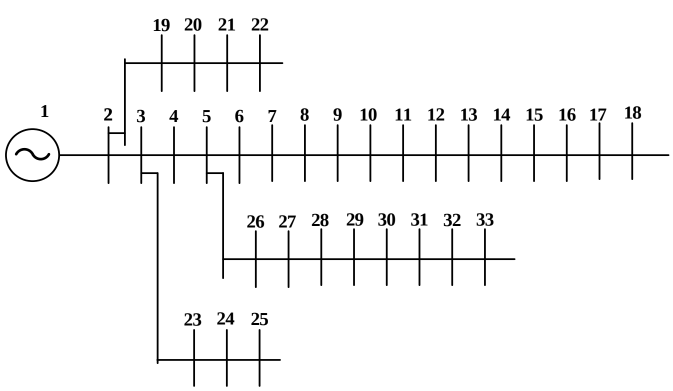

Figure 4. Single-line diagram of the IEEE 33 bus power system.

The maximum limitations are established using the formulas in equations (12) through (13), while the minimum limits for DG and SC are set to zero MW and zero MVAr, respectively.

For each test system, the following cases are examined in order to demonstrate the efficacy of the proposed approaches:

- Case 1: Single shunt capacitor (SC) unit.
- Case 2: Single Distributed Generation (DG) unit.
- Case 3: Single DG and SC units, simultaneously

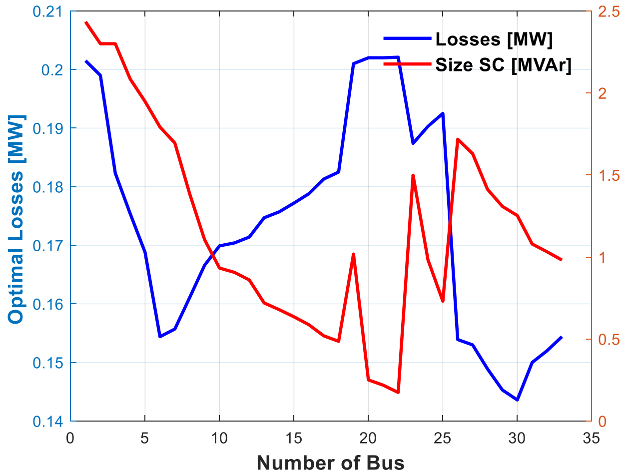

Figure 5. The losses of real power [MW] and size of SC [MVAr] after installation of SC unit at each bus.

Case #1: Single shunt capacitor (SC) unit.

The first case study uses the suggested algorithms, GWO and RM, to show a shunt capacitor's ideal placement and size (SC). Fig. 5 shows the real power losses at each bus, with the best position and sizing determined by RM and GWO, respectively. Table 2 presents the real power losses, minimum voltage stability index (Bus number 18), and minimum magnitude voltage (Bus number 18) for this situation. Bus number 30 will be the chosen site for SC. The SC should be sized at 1.2527 MVAr. In the ideal scenario, real power losses are 0.1436 MW as opposed to 0.2015 MW in the initial example. The optimal real power loss reduction rate dropped to 28.74%. Table 2 illustrates the lowest voltage (stated in bus number 18), which is decreased from 0.913 [p.u.] at the initial case to 0.926 [p.u.] at the ideal case (after adding SC to this system). Furthermore, installing an SC affects the voltage stability index (VSI). After adding SC, the optimal case's minimal value of VSI (Bus number: 18) increased from 0.6960 at the beginning to 0.73498 at the end. In the ideal case study, the GWO method decreased the reactive power losses from 0.1343 MVAr to 0.0959 MVAr.

Case #2: Single distributed generation (DG) unit.

The second instance in this research illustrates the ideal placement and scale for distributed generation (DG) using GWO and RM. Fig. 6 shows the real power losses at each bus, with the best position and sizing determined by RM and GWO, respectively. Table 2 presents the ideal real power losses, minimal magnitude voltage, and voltage stability index results for all buses in this example, including Bus number 18.

The best place for DG will be chosen on bus number 6. The ideal DG sizing is 2.575 [MW]. Real power losses decreased from 0.2015 [MW] in the original instance to 0.1037 [MW] in the best-case scenario (after the installation of a single DG unit). The optimal real power loss reduction rate dropped to 48.53%. Table 2 illustrates how the minimum magnitude voltage (recorded in bus number 18) is lowered from 0.913 [p.u.] at the beginning case to 0.9511 [p.u.] at the optimal case (following the installation of DG in this system). In addition, the installation of DG affects the voltage stability index (VSI). The minimum value of VSI (Bus number is 18) increased from 0.6960 at the initial case to 0.8191 at the optimal case (after installing DG); additionally, reactive power losses decreased using the GWO algorithm from 0.1343 [MVAr] to 0.0746 [MVAr] at the optimal case.

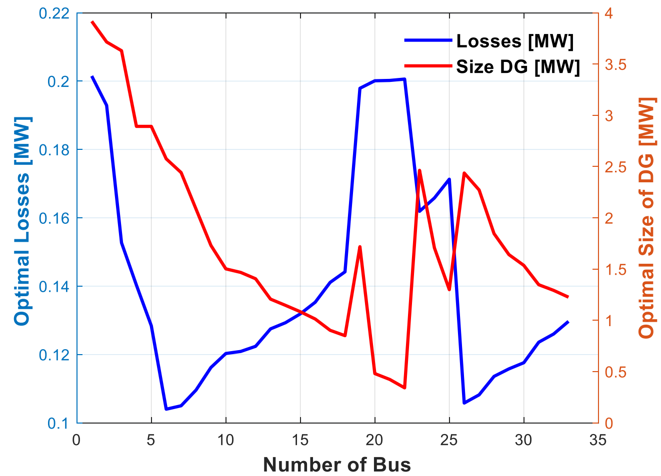

Figure 6. The losses of real power [MW] and size of DG [MW] after installing the DG unit at each bus.

Case #3: Single shunt capacitor (SC) and distributed generation (DG) units.

The third case in this paper shows how to use GWO and RM to determine the ideal placement and size for a single SC and DG. The best place (Bus number) to install a SC unit is 30, while the best place (Bus number) to install a DG unit is 6, according to the authors' analysis of prior situations. Table 2 reports the optimal real power losses, minimum magnitude voltage, and voltage stability index at all buses (Bus number 18). Fig.7 shows the convergence characteristics of real power losses using Grey Wolf Optimizer (GWO), considering that the number of populations is 50 and the number of iterations is 50. The optimal size for the SC and DG units is 1.2492 [MVAr] and 2.5195 [MW], respectively.

Table 2. The optimal results of GWO.

Items	Initial	After Installation		
		SC	DG	SC & DG
Total RPL [MW]	0.2015	0.1430	0.1037	0.05173
Tot. QPL [MVAr]	0.1343	0.0959	0.0746	0.04041
Reduction rate %	—	28.74	48.53	74.3
Min voltage [p.u.]	0.913	0.926	0.9511	0.9622
Minimum VSI	0.696	0.735	0.8191	0.8582
Sum of VSI	26.901	28.16	29.87	31.151
Size SC [MVAr]	—	1.253	—	1.2492
Size of DG [MW]	—	—	2.5753	2.5195

After installing single Qc and DG units, the optimal case's real power losses were reduced from 0.2015 [MW] to 0.05173 [MW]. The optimal real power losses also had a percentage reduction rate of 74.3%. The minimum magnitude voltage (reported in bus number 18) has been reduced from 0.913 [p.u.] at the initial case to 0.9622 [p.u.] at the optimal case (after installation of single SC and DG units to this system), as shown in Table 2. The minimum value of VSI (Bus number is 18) has been increased from 0.6960 at the initial case to 0.8582 at the optimal case (after installation of single SC and DG units). Also, the reactive power losses were reduced from 0.1343 [MVAr] to 0.0404 [MVAr] in the optimal case using the GWO algorithm.

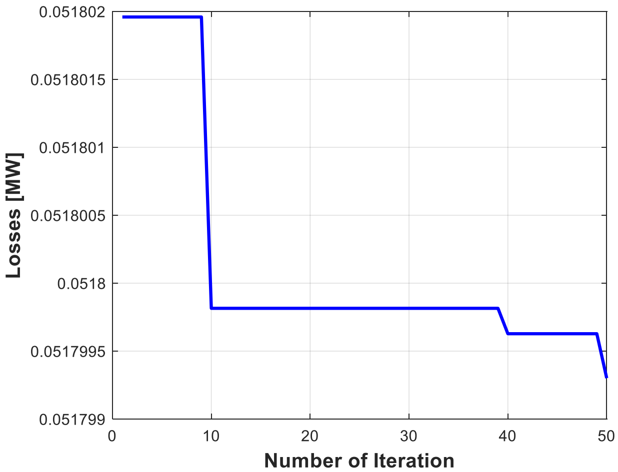

Figure 7. The convergence characteristics of real power losses [MW] after SC and DG unit installation.

The authors compared the outcomes of this method with other optimization techniques, as indicated in Table 3, to illustrate the efficacy and superiority of the proposed approach GWO. Fig. 8 and Fig. 9 show how the installations of single SC and single DG effects on the voltage profiles and the voltage stability index (VSI).

Table 3. Comparison of the result obtained by GWO with other methods after installation single DG unit.

Method	Initial loss [MW]	After Installation DG loss [MW]	Size [MW]	Bus	Red. Rate %
IWD [29]	0.2112	0.1110	2.49	6	47.46
BB-BC [30]	0.2110	0.1082	2.58	5	48.70
MINLP [31]	0.2110	0.1110	2.59	6	47.39
Analy. [32]	0.2112	0.1112	2.49	6	47.33
PSO [33]	0.2110	0.1153	3.15	6	45.36
PSO [34]	0.2110	0.1188	2.49	6	43.68
GWO [35]	0.2120	0.1114	2.762	6	47.19
GWO	0.2015	0.1037	2.575	6	48.53

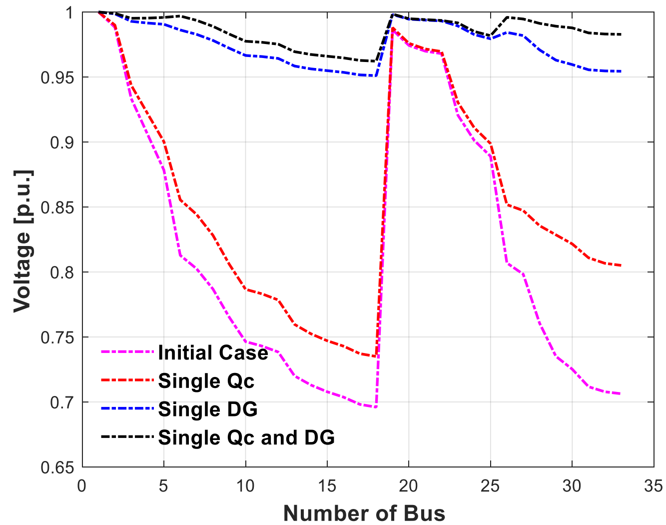

Figure 8. Voltage profile for three cases using GWO.

5. Conclusion

In this study, the authors used two approaches to determine the optimal sizing and location of a single shunt capacitor (SC) and a single distributed generator (DG) on distribution networks. The first approach is to calculate and determine the optimal size of the shunt capacitor and distribution generators by the Grey Wolf Optimizer (GWO) algorithm. The second approach is responsible for determining the optimal location by the reconfiguration method (RM). The main aim of determining the optimal size and location of SC and DG is to minimize the total real power losses of distribution lines, reduce the reactive power losses, improve the voltage deviation, and enhance the voltage stability index of the whole system. The IEEE 33-bus standard radial network was developed to show the viability and efficiency of GWO and RM performance. The best outcomes produced by the suggested algorithm GWO demonstrated its superiority and efficiency by greatly lowering the overall losses of both reactive and actual power, strengthening the voltage profiles, and raising the voltage stability index. The GWO and RM effectively found the best answers to the issue, especially when figuring out where and how big SC and DG should be put. The results show that the suggested methods, GWO and RM, are quite appropriate for figuring out where and how big to assign SC and DG units in distribution networks. The suggested approach's primary benefits are that it is simple to use, requires little computational work, finds workable solutions, and produces optimal or nearly ideal results.

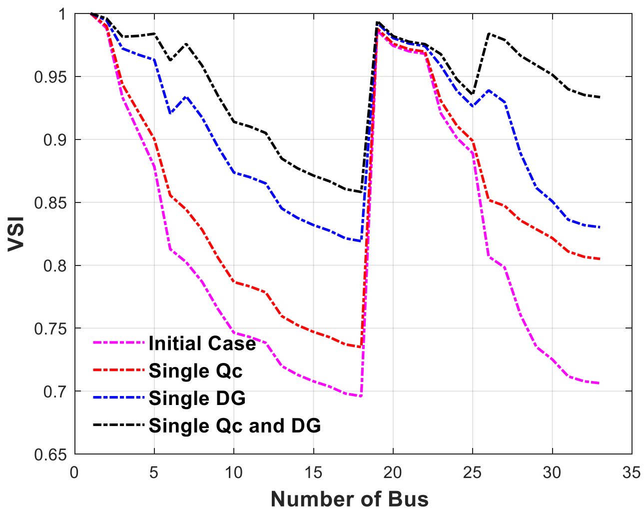

Figure 9. Voltage stability index for three cases using GWO.

Figs 10 and 11 illustrate the comparison results of real and reactive power losses between the initial case and three cases (after installation of a single SC, single DG, or single SC and DG simultaneously). From this figure, the best case will be the installation of a single SC and DG simultaneously.

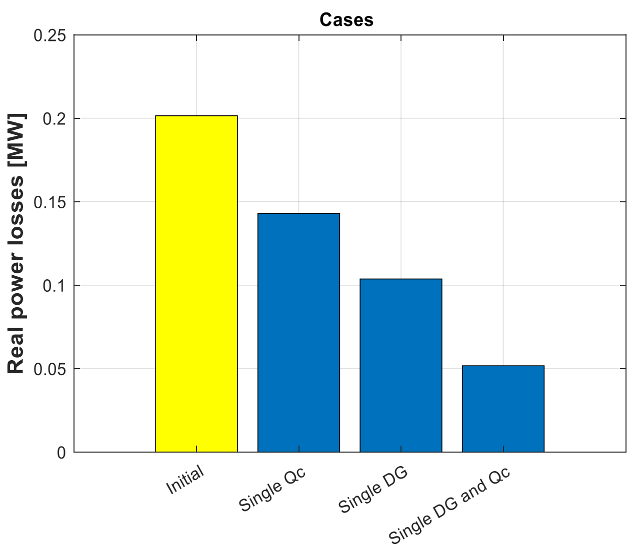

Figure 10. Comparison results of real power losses.

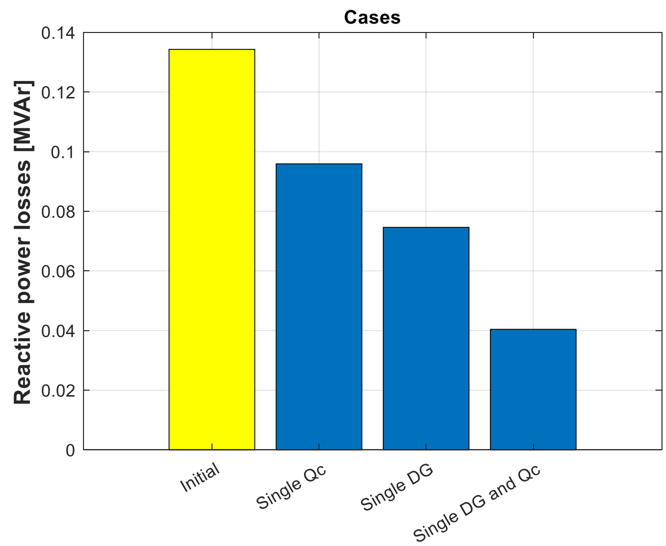

Figure 11. Comparison results of reactive power losses.

Abbreviations

RPL	Real power system
QPL	Reactive power losses
GWO	Grey Wolf Optimizer
VD	Voltage deviation
VSI	Voltage stability index
SC	shunt Capacitor
DG	Distributed generators

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Bahaa Hussein Al IGEB proposed conceptualization, methodology, and writing—original draft preparation.

Petr P. Oshchepkov verified the analytical methods and investigated and supervised the findings of this work.

Mazin T. Muhssin: writing—review and editing

Murtadha AL-KAABI developed the software and formal analysis.

Ali Abdulazeez proposed the data curation

Saad K. Khalaf validation and investigation

All authors discussed the results and contributed to the final manuscript.

Data Availability

The data supporting the reported results are available in the manuscript.

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